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Small-Scale Vertical Flammability Testing for Fabrics*‡

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ABSTRACT

Many small-scale vertical flammability tests have been designed to assess 'self-extinguishment' of fabrics after exposure to a small flame, where self-extinguishment refers to the cessation of flaming or glowing of the specimen upon removal of the ignition source. The specimens are held vertically in a U-shaped metal frame and ignited at the bottom. The criteria chosen for these tests are char length, afterflame, afterglow, and melt drip. These tests were first promulgated in the 1930*s for use on flame-retardant cellulosics and wools. The applicability of the test to char-forming as well as thermoplastic fabrics will be discussed.*

INTRODUCTION

This paper raises some questions regarding present, well established test methods of testing fabrics for resistance to small flame ignition sources. Specifically, we question (1) are present test methods relevant to the actual hazard; (2) do the methods or the limiting criteria impose

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unnecessary requirements on manufacturers of certain popular products; and (3) could the many methods be replaced by one single method?

HISTORICAL PERSPECTIVE

It is not at all unusual that the application of a well established flammability test is extended to non-realistic application testing or that the test method becomes obsolete in the face of new technological developments and materials. A case in the first point is of the 'tunnel test', ASTM E 84, developed to test the fire hazard of wall and ceiling interior finishing materials, but then used to rate floor-coverings when the use of carpeting became more widespread.[1] This involved exposing the face of the carpets, upside down, to a large ignition source and measuring flame spread rate. Thermoplastic carpets melt and drip (ablate) and often exhibit low flame spread in the tests, but not necessarily in real-life fires. Consequently, a separate test was developed for floor-coverings and carpets in which the specimens are exposed under more realistic test to conditions more similar to their full-scale fire behavior; ASTM E 648 which was specifically designed to apply to floor-coverings was a result of those efforts.[2]

Another example of non-realistic application testing is single-layer component testing of multiple-layer constructed curtains and drapes. Currently, the NFPA 701 test method is specified in codes for testing and certifying drapery fabrics. The test method evaluates the fabric in a single layer; however, most drapes are constructed in multiple layers. Recent full-scale experiments showed that a multiple-layer drape made from a char-former and a thermoplastic material burned vigorously.[3] Both of these materials met the specified criteria of NFPA 701 when tested individually. The vigorous fire, with the multiple-layer drape, occurred when the molten thermoplastic adhered to the char-forming layer, thus causing a sustained propagation. The existence of this phenomenon has been described in the 1989 version of NFPA 701.[4] To address this problem, the Center for Fire Research is presently working with the American Textile Manufacturers Institute and the American Fiber Manufacturers Association to develop guidelines for a more meaningful test for multiple layers of fabrics. (This project involves the examination of small and mid-size tests, as well as full-scale tests of multiple layers of drapes and curtains. The objective of the project is to examine the feasibility of using small-scale tests to simulate full-scale multiple-layer drapery fire tests.)

TABLE 1
Small-Scale Vertical Textile Flammability Test Methods[a,b]

Organization	*Name of test*	*Designation no.*	*Material*	*Specimen size (mm)*[c]	*No. of specimens*	*Ignition source and time*	*Condition*	*Properties measured*
Canvas Product Association International[d]	Flame resistant materials used in camp. tentage wall & top	CPAI-84	Tentage	70 × 305	4W[e] 4F[f]	Burner Matheson Gas B (12 s)	21 °C 65% RH	After flame, char length
National Fire Protection Association[g]	Fire tests for flame resistant textiles & films	NFPA-701 small scale	Fabrics & films	89 × 254	5W 5F	Burner (12 s)	Oven-dry 60 °C	After flame, after glow, char length, melt drip
National Fire Protection Association	Fire tests for flame resistant textiles & films	NFPA-701 large scale	Fabrics & films	610 × 2134 folded, flat, no frame	4 10	Burner (2 min)	Oven-dry 60 °C	After flame, char length, melt drip
National Fire Protection Association	Fire tests for flame resistant textiles & films	NFPA-701 field test	Fabrics & films	38 × 102 no cabinet, no frame	1	Wooden match (12 s)	Ambient	Char length, after flame, melt drip
Federal Test Method Standard	Flame resistance of cloth	Method 5902 FTMS 191A	Fabrics	70 × 305	5W 5F	Burner (12 s)	21 °C 65% RH	After flame, after glow, char length

(continued)

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Organization	*Name of test*	*Designation no.*	*Material*	*Specimen size (mm)*[c]	*No. of specimens*	*Ignition source and time*	*Condition*	*Properties measured*
Federal Test Method Standard[h]	Flame resistance of cloth	Method 5903 FTMS 191A	Fabrics	76 × 305	5W 5F	Burner Methane (12 s)	21 °C 65% RH	After flame, after glow, char length
Federal Test Method Standard	Flame resistance of cloth field test	Method 5904 FTMS 191A	Fabrics	51 × 127 no cabinet	3	Candle (12 s)	Ambient	After flame, char length
Federal Test Method Standard	Flame resistance of material: high heat flux	Method 5905 FTMS 191A	Fabrics	70 × 305 no cabinet, no frame	5W 5F	Burner Butane (12 s)	21 °C 65% RH	Shrinkage, after flame
City of Boston	Fire Code 1959	Article 11	Flammable decorations	38 × 254 no cabinet	3	Burner (10 s)	Ambient	After flame, after glow
City of New York	Fire Code 1940	Para. 5·0	Fabrics	50 × 318	3	Burner (12 s)	21 °C 40% RH	After flame, after glow
State of California	Fire code Title 19	Para. 1237·3 small-scale	Fabrics	64 × 318	3W 3F	Burner (12 s)	Oven-dry 60 °C	Char length
Consumer Product Safety Commission	Children's sleepwear	DOC FF3-71 DOC FF5-74	Sleepwear 0–6X 7–14	89 × 254	3W 2F 15-seams	Burner (3 s)	Oven-dry 105 °C	Char length
American Association of Textile Chemists & Colorists	Fire resistance of textile fabrics	34-1966	Fabrics	70 × 254	3W 3F	Burner Matheson Gas B (12 s)	21 °C 65° RH	After flame, After glow, char length

American Society of Testing & Materials	Semi-restraint test	D 3659-86	Fabrics	152 × 381 no frame	5	Burner (3 s)	Oven-dry 105 °C	After flame, weight loss, char area
American Society of Testing & Materials	Flame resistance of aerospace materials	F 501-88	Fabrics & Materials	70 × 35	3	Burner (12 s)	21 °C 50% RH	After flame, after glow, flame drip
British Standard	Flammability of fabrics	Method A BS 2963	Fabrics	40 × 1830	6	Burner (12 s)	21 °C 65% RH	After flame
Canadian Standard	Test method for flame resistance vertical test	27·1-M77 1977	Fabrics	50 × 315 no frame	—	Burner (12 s)	—	Flashing, after flame after glow, char length, melt drip, shrinkage
German Federal Republic Standard	Burning behavior of fabrics	DIN 53906	Fabrics	75 × 340	—	Burner Propane (3 & 15 s)	21 °C 65% RH	After flame, after glow, char length, melt drip

[a]Tests listed utilize a cabinet, metal frame, and methane gas unless specifically noted in the test description.
[b]This listing has no legal significance and is not intended to be all inclusive.
[c]To obtain approximate dimensions in inches, divide by 25·4.
[d]CPAI-84, wall & top material test, is an equivalent test to ASTM D4372.
[e]W, Warp or machine direction.
[f]F, Filling or cross direction.
[g]NFPA 701 is utilized by Federal Aviation Administration 25·853, and Canadian Standard ULC-S109.
[h]Federal Test Method 5903 is utilized by Port Authority of New York and New Jersey, and the US. Veterans Administration.

It is entirely possible that problems of a different nature exist for the single-layer fabric tests. Many of these tests are listed in Table 1. The principle of these tests is to define 'self-extinguishment' of the fabrics, where 'self-extinguishment' is defined by cessation of flaming or glowing of a vertical specimen, mounted in a U-shaped frame, after removal of a small igniter flame. As seen in Table 1, the tests differ mostly in minor details, e.g. preconditioning of the specimens, specimen size, ignition source, etc. Others, e.g. the ASTM D 3659 semi-restraint test and the NFPA 701 Large-Scale test differ by dispensing with the specimen frames, allowing the specimens to shrink, move, etc. Figure 1 shows the basic arrangement of most of these tests. Many other tests are used to evaluate fabrics which propagate flame, the criterion usually being flame spread rate; these will not be discussed here.

Many of these test methods were adopted when only flame-retardant-treated cellulosic (primarily cotton and linen), and protein (wool and silk) textiles were available. Thermoplastic fibers such as nylon, olefin and polyester, were developed five to twenty years later. Even in flammability tests developed since the advent of these newer fibers, the principal features of the previous test procedure were retained. However, natural and thermoplastic fabrics differ significantly in their

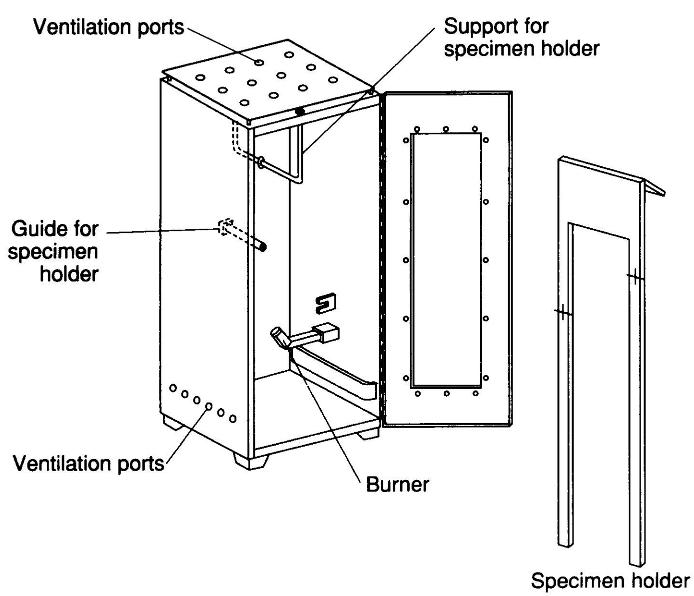

Fig. 1. Typical small-scale vertical textile testing apparatus.

response to a flaming ignition source. In simple terms, the flame-retardant-treated cellulosic and wool fabrics form chars when exposed to an ignition source; in such fabrics, the char formation acts as a means to minimize further flame spread. On the other hand, many thermoplastic fabrics shrink, melt and/or drip when exposed to a bottom flame. The mechanism by which they could pass the test then consists either of withdrawal of the fabric from the flame and/or of non-propagation of a flame applied to the bottom edge as the molten polymer moves downward. They may still burn when exposed to other ignition conditions, e.g. application of the flame in the body of the specimen and/or different ignition sources.

HEAT RELEASE TESTS

There are a number of tests which are intended to measure the behavior of materials when they are exposed under conditions of a large fire. These tests are intended to predict the contribution of various materials to the outcome of relatively large fires. Among them are:

—The proposed Room Fire Test,[5] presently under discussion in ASTM E-5 Subcommittee EO5·13, which measures time to flash-over and heat release of materials mounted on the walls of a room.
—Two small-scale tests which measure the rate of heat release under irradiance levels which approach those found in real fires: proposed ASTM E-1354, 'Heat and visible smoke release rates for an oxygen consumption calorimeter' (Cone Calorimeter)[6] and ASTM E 906-83. 'Heat and visible smoke release rates for materials and products' (Ohio State University Calorimeter-OSU).[7]

These three tests are not widely used at present for fabric products but are discussed here because their application may be forthcoming for composite structures which utilize fabrics. The OSU Calorimeter test has recently been written into the Federal Aviation Administration specifications for interior products for airplanes.[8] The Cone Calorimeter test has been used to study rate of heat release for ship composites[9] and upholstered furniture.[10] The ASTM Room Fire Test has been used to evaluate commercial wallcoverings.[11] Because these tests are relatively new the principal features of these tests are described in Table 2.

TABLE 2
High Radiant Flux Flammability Test Methods

Test method	*Designation no.*	*Sample size (mm)*	*Ignition source*	*Flux level exposure* (kW/m^2)	*Time of exposure*	*Performance measure*
Room fire test of wall & ceiling materials & Assemblies	ASTM E-5 subcommittee EO5·13 (proposal)	Material covers adjacent 2 walls; room size 2·4 m × 3·7 m × 2·4 m	Burner (96% propane) diffusion flame	max 176 kW	15 min 3-step exposure of various flux levels	Time to flashover, heat release rate
Oxygen consumption calorimeter (Cone)	ASTM E-1354	100 × 100 × 50	Conical heater Spark ignition	0–100	Continuous exposure	Heat release rate, average heat release, total heat release, sample mass loss, smoke obscuration, time to ignition
Ohio State calorimeter (OSU)	ASTM E 906-83	150 × 150 × 100	Flame pilot ignition (90% methane)	0–100	10 min	Heat release rate, smoke release rate, time to ignition

VERTICAL FLAMMABILTY TESTS

In the following list, some questions arising from the use of the current fabric tests, in which the fabric is suspended in vertical metal frames and a small flame is applied to the bottom edge, are discussed. Because the present test methods are critically reviewed from a variety of points of view, a certain amount of redundancy will be found:

—Number of test methods: is there a need for such a variety of tests, differing, in most instances, in minor details? Table 1 lists many of these tests. A research project could possibly be conducted to determine whether it is feasible to select a single standard test. This should result in considerable simplification of certification procedures.

—Char-forming versus thermoplastic fabrics: on the one hand, should there be different small-scale procedures for char-forming and for thermoplastic fabrics, in view of their very different burning modes? A case can be made that, for char-forming fabrics, the present tests have stood the test of time. Indeed, bottom ignition may represent the worst case situation in small-scale flaming ignition for these fabrics. On the other hand, it is not clear that thermoplastic fabrics are properly evaluated by their 'char length' (actually in most cases primarily a measure of the length of the specimen area destroyed by heat shrinkage and ablation) resulting from bottom ignition. It may be possible that such fabrics may be better evaluated by application of the flames in the body of the specimen; it is not known whether that would affect the present concept of self-extinguishment for char-formers.

—Correlation of small and large-scale test results: why do some fabrics sometimes fail to meet present small-scale test criteria, yet they meet perhaps more realistic NFPA 701 Large-Scale test criteria where the specimens are not restrained in frames but hang freely?[12] Thermoplastics often do not meet the criteria of the small-scale tests because molten material may accumulate near the frame edges and continue to burn, albeit tenuously, with very little heat output, while in the large-scale test the fabric shrinks and moves away from the flame. For char-forming fabrics this generally does not occur. Obviously, a small-scale test providing better correlation with large-scale tests would be desirable.

—Are the igniter flames appropriate? The objective here would be to evaluate by means of experimental design the effects of flame variables in large and small-scale tests to assure good correlation. Specifics are discussed below.

- Flame configuration: are the present flame configurations appropriate to all types of fabrics to which the self-extinguishment criteria are applied? Durbetaki *et al.* had shown that thermoplastics are more readily ignited by a microburner diffusion flame than by an intensive, large premixed flame.[13] They also discussed the relative effect of diffusion and premixed flames on char-forming and thermoplastic specimens. Diffusion flames did not cause as much shrinking or ablation because the specimen remained in closer contact with the flame and therefore was more readily ignited. The premixed flame caused more melting and shrinking of the material surrounding the flame, therefore decreasing contact between the flame and specimen. It was also found that a diffusion flame generally is slower to melt thermoplastics and slower to ignite cellulosics than a premixed flame.
- Time of exposure to the flame source: how does time of specimen exposure to the flame contribute to the test results? Longer exposure times have occasionally been shown to produce shorter char lengths in flame-retardant-treated cotton fabrics.[14] McCarter hypothesized that 'flame-retardant' vapor is released upon heating; the char length in such cases can depend on the total time of flame exposure as well as on the rate of the development of such vapors. If the time of exposure is decreased, insufficient flame retardant vapor may be released and a longer char length is obtained. We have observed that once the thermoplastic material has melted away from the flame, there will be very little contact between the flame and the specimen, and generally there will be no ignition even at very long exposure times.
- Location of ignition source: is a bottom edge ignition meaningful for all fabrics? As discussed earlier, thermoplastic fabrics often meet the criteria by virtue of the fact that they shrink away from the flame applied to the bottom edge and ablate, rather than char, and then self-extinguish. When some types of thermoplastics are ignited by a small flame in the body of the fabric, they burn sideward and downward, albeit slowly. Ablation, or the falling away, of fairly large, flaming fabric segments can then occur, which may lead to ignition of items on the floor.

—Use of specimen frames: do framed specimens correctly characterize the hazards presented by char-forming as well as thermoplastic materials in actual use? By restricting shrinkage of thermoplastics away from the flame and causing them to burn tenuously on the frame edge, such fabrics may fail to meet the char length criteria. However, in a less restrictive configuration, e.g. in the semi-restraint test and the NFPA 701 Large-Scale Test where the specimens are held firmly in place at the top edge only, or in actual use, these fabrics may perform differently.

—Limiting criteria: with respect to choice of limiting criteria, what does a specified char length indicate about the relative hazard of a fabric? Does a char length of 4 in (10·2 cm) indicate a safer fabric than a char length of 7 in. (17.8 cm)? Has this ever been proven by full scale tests? It should be noted that considerably heavier (and more expensive) flame retardant application is needed to produce cotton fabrics with 4-in. (10·2 cm) rather than with 7-in. (17·8 cm) char length. Perhaps it would be better to base limiting criteria on the heat released by the specimen, before it extingishes, in order to determine its contribution to fire growth. Possible ways to do this would be to measure heat output of the specimens after flame removal or mounting a flammable material near the specimen and observing ignition or non-ignition.[15] For thermoplastics which may drip or ablate, it may be appropriate to place a reasonably flammable material under the specimen as an indicator of secondary ignition. Note that, e.g. the German Federal Republic Building Materials Test DIN 4102, has a provision for placing filter paper under the specimen, and observing ignition/non-ignition of the paper.[16]

—Flammability behavior of fabrics in large fires: finally, it should be kept in mind that the present small-scale flammability tests do not predict how the fabrics may behave when exposed to a large ignition source or considerable radiant heat. A fabric will probably behave differently because textile flame retardant finishes are primarily intended to prevent ignition by small, direct heat sources. Testing with irradiance imposed on the specimen as in the heat release rate tests mentioned earlier[6,7] would provide additional information on the behavior under more severe conditions and may provide a more complete estimate of the total fire hazard of a fabric.

CONCLUSIONS

In summary, we have tried to critically review the validity of the common test methods used to evaluate ignitability of so-called self-extinguishing fabrics; a number of questions relative to the adequacies of the present procedures has been raised. It appears that additional research should be performed to assess whether these methods are appropriate to all current materials in the market place. The process would be to conduct a number of full-scale tests of present materials and to develop a test procedure and criteria which correlate to the full scale results. Such research should assure that the test method and criteria are directly related to a measure of the potential hazard in the context of its intended use.

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